UNITED STATES AIR FORCE
RESEARCH LABORATORY

ISSUES FOR DATA REDUCTION OF DENSE THREE-DIMENSIONAL DATA (U)

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20010426 004

JANUARY 1998

FINAL REPORT FOR THE PERIOD JANUARY 1996 TO MARCH 1997

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TECHNICAL REVIEW AND APPROVAL

AFRL-HE-WP-SR-2001-0008

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

MARIS M. VIKMANIS
Chief, Crew System Interface Division
Air Force Research Laboratory

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 074-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	January 1998	Final Report, January 1996 – March 1997

4. TITLE AND SUBTITLE

Issues for Data Reduction of Dense Three-Dimensional Data

5. FUNDING NUMBERS

PE 65502F
PR 2300
TA CH
WU 51

6. AUTHOR(S)

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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

**Air Force Research Laboratory, Human Effectiveness Directorate
Crew System Interface Division
Air Force Material Command
Wright-Patterson AFB, OH 45433-7022

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

AFRL-HE-WP-SR-2001-0008

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 Words)*

Acquiring a large quantity of three-dimensional data has become commonplace with the advent of new technologies. Reducing the number of data points improves processing speed and storage requirements. Astute data reduction requires an understanding of the correlation between data measures and geometric measures. These relationships are dependent upon the data reduction algorithm used. This paper investigates these relationships for a small number of data reduction algorithms. A framework is presented for tracking these changes and for assisting a user in identifying the most appropriate data reduction method for their application.

14. SUBJECT TERMS

Data reduction, three-dimensional imaging

15. NUMBER OF PAGES

12

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UNLIMITED

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Issues for Data Reduction of Dense Three Dimensional Data

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ABSTRACT

Acquiring a large quantity of three dimensional data has become common place with the advent of new technologies. Reducing the number of data points improves processing speed and storage requirements. Astute data reduction requires an understanding of the correlation between data measures and geometric measures. These relationships are dependent upon the data reduction algorithm used. This paper investigates these relationships for a small number of data reduction algorithms. A framework is presented for tracking these changes and for assisting a user in identifying the most appropriate data reduction method for their application.

Keywords: data reduction, three dimensional imaging

1. INTRODUCTION

Acquiring dense three dimensional data of physical objects has become more prevalent due to advances in laser triangulation systems, ultra-sound, MRI, CAT scans, etc. The data may be treated as vertices of polygons to assure topological consistency. Many scanned objects are composed of millions of polygons to describe their surface data and demand extensive computational power for analysis. This large volume of data representing an object is rarely needed for specific applications. Reducing the number of data points improves processing speed and reduces storage requirements. Intelligent data reduction requires an understanding of the application for the data as well as the geometry of the acquiring system.

Different applications using the same three dimensional data can tolerate varying degrees of reduction. For example, using a small number of polygons improves the performance of simulation systems. Reducing polygons achieves faster refresh rates and is a high priority for visualization purposes. A higher resolution, however, is required for shape analysis. Geometric measurements, such as linear distances between points, are often extracted from three dimensional images of an object. Unmanaged and unquantified reduction of the resolution may degrade the integrity of the surface data, resulting in inaccurate measurements.

Data reduction methods exist which (1) reduce polygons uniformly and (2) reduce the number of polygons adaptively based on a cost function. Uniform data reduction does not discriminate between areas of high and low information content, resulting in distortions. Reduction of data based on cost functions (typically distance to a plane) maintains better surface definition. Both methods fail to quantify the degree to which the geometric description of the object has changed. An intelligent data reduction scheme is needed which allows the user to establish the criteria, based on geometric measures, for guiding the elimination of data and converging to an optimal polygon mesh.

This paper investigates methods and criteria that can be used to establish the trade-off costs between model distortion and data reduction. In Section 2, several measurements important to three dimensional data reduction are classified and discussed. Section 3 presents a limited number of data reduction methods and their relationship to geometric measures. Section 4 presents a format for incorporating this information into a user friendly GUI. In this manner, the user can define tolerable shape degradation with respect to a particular application. Section 5 presents a conclusion.

2. MEASUREMENTS OF INTEREST

This section presents a list of measures which the authors have found relevant for their own work or appear prominently in the literature. The measurements have been placed into two categories. The first category are measurements made with the three dimensional data that can be verified by the physical object. The second category are measurements implicit to discrete three dimensional data points. These are the measures that are typically used to guide data reduction.

2.1 Geometric Measures:

Point to point distance - The linear distance between two feature points of a physical object is often required. Obtaining this measurement from a three dimensional data image of the object may require interpolation if the desired feature points were not captured.

Curvature - Curvature measures on surfaces, using the broadest definition, can include measurement of arc, angle, radius and profile. Obtaining these measures from three dimensional data requires a variety of techniques, some of which are not well defined.

Surface area - For all but the simplest physical forms, surface area calculations require sampling and approximating the object.

Volume - For all but the simplest physical forms, volume calculations require sampling and approximating the object.

Center of gravity - The center of gravity of an object can be determined with minimum shape information. To determine this value from a three dimensional data set requires assumptions about the object's density. Higher order moments can also be calculated.

2.2 Data Measures

Reduction in data - With data reduction as the stated goal, this is arguably the most important measure considered in this paper. It is also very difficult to predict priori for many data reduction algorithms.

Change original data - Many data reduction algorithms use the original data set to fit a sparser control set. The original data set is then discarded. An important concern of this method is that measurement errors of the original data set are known by the characteristics of the sensor, whereas, the errors projected to the control set may not be well understood.

Distance to an implicitly defined surface - Data reduction has been achieved be eliminating redundant data points that define the same surface. The most commonly used surface is the plane.

Statistical distance to a fitted surface - Data reduction can also be achieved by fitting a surface to the data, using for example least square error.

Maximum distance between data points - Techniques which attempt to achieve a minimum number of original data points will increase the sampling distance of the data. This has implications to maximum resolution of the data.

3. MEASUREMENT DEPENDENCIES

The relationship between geometric measures and data measures will vary depending upon the reduction algorithm. The three dimensional scanning system used will also have an effect. The reduction algorithms considered in this paper are limited to polygon reduction and surface fitting.
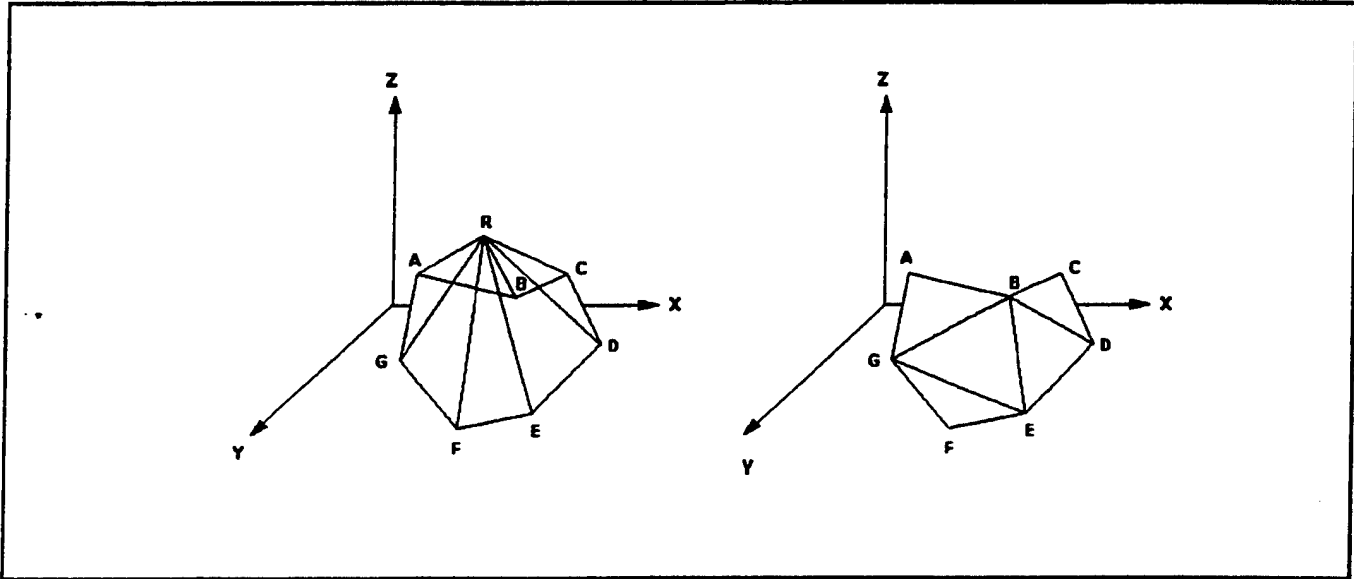

Figure 1. Illustration of vertex elimination.

An example of polygon reduction is illustrated in Figure 1. The polygon mesh, consisting of vertices and edges, represents surface information in a patchwork of triangular faces. As vertices are eliminated and the patch re-triangulated, definition of the surface is reduced. The example illustrated simplifies data reduction, but illustrates one method (vertex elimination) used to reduce the size of the mesh. Other methods available include edge swap, edge collapse, and edge split which change the geometric description of the object's surface.

We consider the polygon reduction method based on the work of Schroeder et.al.[1] This algorithm maintains the original data, eliminating points that are coplanar to within some tolerance of a larger polygon. Polygon reduction methods that generate new data points, such as those proposed by Turk et.al.[2] and Hoppe et.al.[3], are not considered in this paper but are currently under investigation. Below is a summary of selected data measures and their effect on geometric measures.

Distance to an implicitly defined surface (plane) -
> Point to point distance: Changes in point to point measurements will be most noticeable for measurements on opposite sides of an object. Assume the points of interest were removed by reduction because they fell within the tolerance of a polygon of local points. If both points were outside the final mesh surface of the object, the point to point measurement could change at most by two times the planar tolerance.
> Curvature: Curvature measures should not be significantly effected by data reduction based on nearly planar points. Extremely low Gaussian curvatures, usually of no interest, are removed from the data.
> Surface area: Removal of any data point that is not exactly coplanar will result in a smaller surface area calculation. The sum of the areas of the original polygon mesh will always be greater than the reduced mesh. This change in surface area will be a function of the number of data points removed, the coplanar tolerance and the size of the resulting polygon.
> Volume: The worst case change in volume will result if all eliminated data points happen to fall either inside or outside the final mesh. In this unlikely scenario, the change in volume will be a function of the number of data

points removed, the coplanar tolerance and the size of the resulting polygon.

Maximum distance between data points -

Point to point distance, Volume, Curvature: Changes in the maximum distance between data points, due to data reduction, will not affect these measurements. The tolerance to the resulting plane is the important parameter, as explained above.

Surface area: Removal of any data point that is not exactly coplanar will result in a smaller surface area calculation. This change in surface area will be a function of the number of data points removed, the coplanar tolerance and the size of the resulting polygon which is dependent on maximum distance.

Another method of reducing the three dimensional data is through surface fitting. Several researchers have demonstrated NURBS surface fitting algorithms.[4,5,6] NURBS surface patches require 16 control points and two parameter values. Significant data reduction requires least squares fitting and a resulting smoothing of the data. Below is a brief summary of the relationship between data and geometric measures. Table I presents an overview the dependency between data and geometric measure for the two reduction categories discussed.

Statistical distance to an fitted surface -

Point to point distance: Changes in point to point measurements can only be estimated statistically. A worst case estimate would be [2 (point to point) x 2.3 x standard deviation (95% of the changed points fall within this distance)]

Curvature: Changes in curvature measures are difficult to predict and very dependent on the fitting method. Fitted NURBS have been known to give erratic curvature estimates.

Surface area: The smoother NURBS surface is certain to result in a smaller surface than that calculated using the original polygon mesh. An estimate to this change may be possible using frequency analysis.

Volume: Changes in volume will likely not be significant due to the fact that original data points are equally likely to fall on the interior and exterior of the surface.

DATA MEASURES	GEOMETRIC MEASURES			
	Point to point distance	Curvature	Surface area	Volume
Reduction in data	Polygon reduce: DEPENDENT Surface reduce: DEPENDENT	Polygon reduce: DEPENDENT Surface reduce: DEPENDENT	Polygon reduce: DEPENDENT Surface reduce: DEPENDENT	Polygon reduce: DEPENDENT Surface reduce: DEPENDENT
Change original data	Polygon reduce: n/a Surface reduce: DEPENDENT	Polygon reduce: n/a Surface reduce: DEPENDENT	Polygon reduce: n/a Surface reduce: DEPENDENT	Polygon reduce: n/a Surface reduce: DEPENDENT
Distance to an implicitly defined surface	Polygon reduce: DEPENDENT Surface reduce: n/a	Polygon reduce: INSIGNIFICANT Surface reduce: n/a	Polygon reduce: DEPENDENT Surface reduce: n/a	Polygon reduce: SMALL DEPENDENCY Surface reduce: n/a
Statistical distance to a fitted surface	Polygon reduce: n/a Surface reduce: DEPENDENT	Polygon reduce: n/a Surface reduce: DEPENDENT	Polygon reduce: n/a Surface reduce: DEPENDENT	Polygon reduce: n/a Surface reduce: SMALL DEPENDENCY
Maximum distance between data points	Polygon reduce: INSIGNIFICANT Surface reduce: n/a	Polygon reduce: INSIGNIFICANT Surface reduce: n/a	Polygon reduce: DEPENDENT Surface reduce: n/a	Polygon reduce: INSIGNIFICANT Surface reduce: n/a

Table 1. Relationships between geometric measures and data measures.

4. USER INTERFACE

To better quantify and compare the different algorithms available, an intelligent user interface is proposed to document changes in the reduced data. Figure 2 presents one proposed format for this GUI. In Figure 2, the user indicates the desired properties of the reduced data. The system recommends one of the currently implemented algorithms with parameters to meet these goals. The system uses its knowledge of the algorithm to predict expected changes in the data as shown in Figure 3. Once the data reduction algorithm has been executed, actual changes will be displayed (Figure 4). Post calculations on the data will not likely be necessary after sufficient validation of the estimating techniques.

5. CONCLUSIONS

A quantitative and uniform method to resolve application driven trade-offs with three dimensional data set reduction will make choosing among algorithms significantly easier. An intelligent graphical interface is described with knowledge of geometric and data relations that will enhance the utility of three dimensional imaging in support of several applications.

6. ACKNOWLEDGEMENTS

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DATA MEASURES

Percentage reduction of data:

DESIRED:
ESTIMATED:
ACTUAL:

Change in original data:

DESIRED:
ESTIMATED:
ACTUAL:

Distance to an implicitly defined surface:

DESIRED:
ESTIMATED:
ACTUAL:

Statistical distance to a fitted surface:

DESIRED:
ESTIMATED:
ACTUAL:

Maximum distance between points:

DESIRED:
ESTIMATED:
ACTUAL:

GEOMETRIC MEASURES

Change in point to point distance:

DESIRED:
ESTIMATED:
ACTUAL:

Curvature:

DESIRED:
ESTIMATED:
ACTUAL:

Percentage change in surface Area:

DESIRED:
ESTIMATED:
ACTUAL:

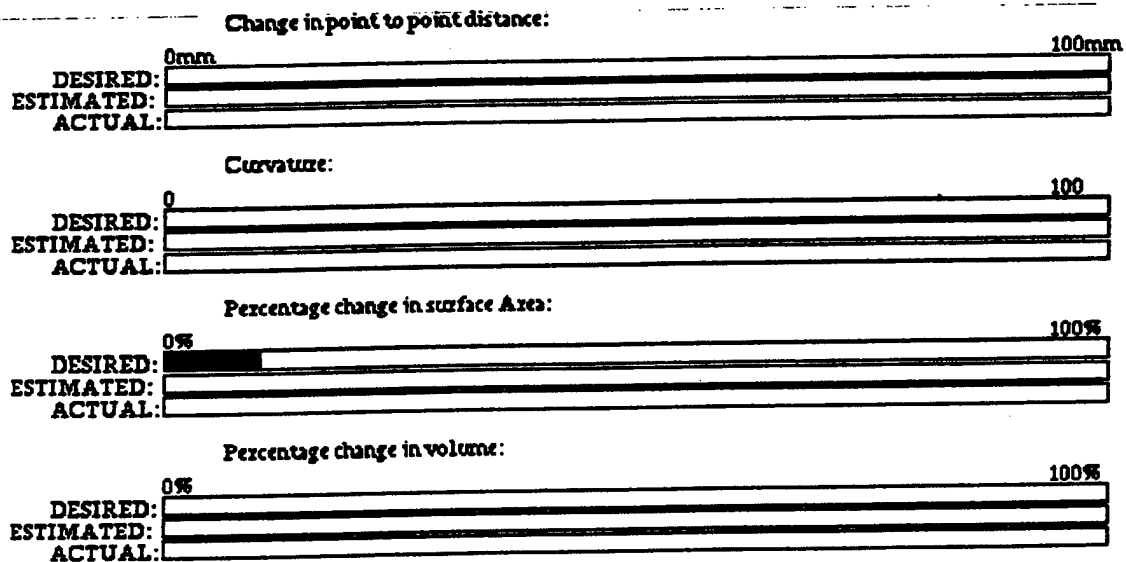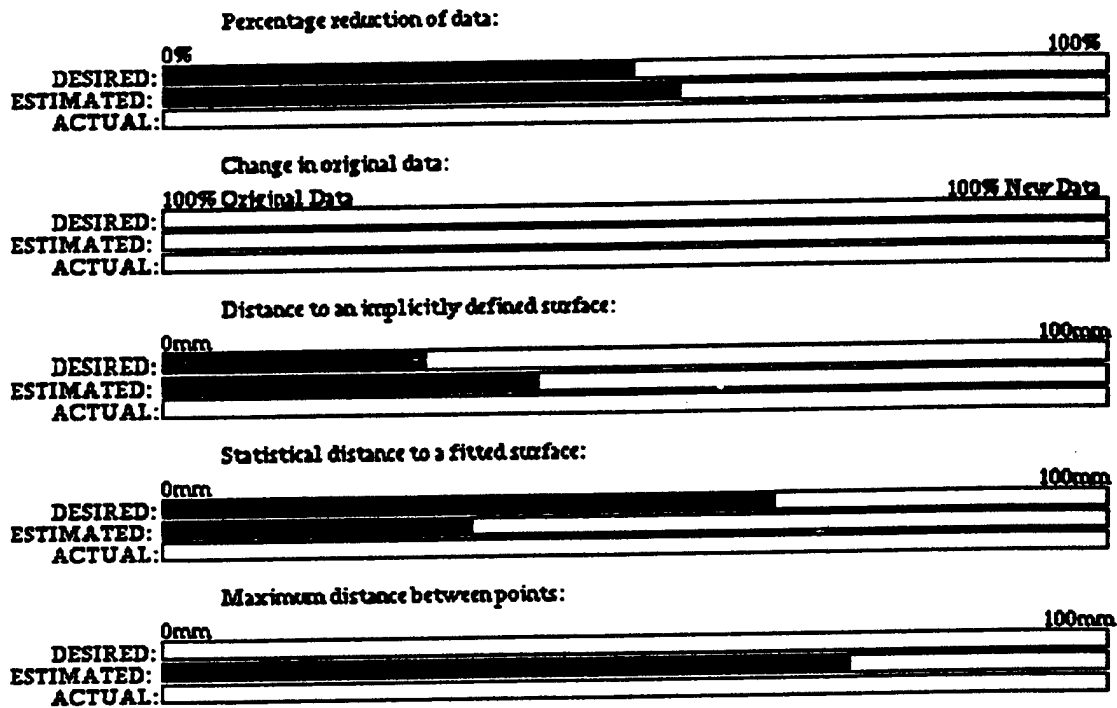Percentage change in volume:

DESIRED:
ESTIMATED:
ACTUAL:

Figure 2. A graphical user interface is proposed to help the user choose a data reduction algorithm. Target goals for changes in the data are specified by the user.

DATA MEASURES

Percentage reduction of data:

0%   100%

DESIRED:
ESTIMATED:
ACTUAL:

Change in original data:

100% Original Data   100% New Data

DESIRED:
ESTIMATED:
ACTUAL:

Distance to an implicitly defined surface:

0mm   100mm

DESIRED:
ESTIMATED:
ACTUAL:

Statistical distance to a fitted surface:

0mm   100mm

DESIRED:
ESTIMATED:
ACTUAL:

Maximum distance between points:

0mm   100mm

DESIRED:
ESTIMATED:
ACTUAL:

GEOMETRIC MEASURES

Change in point to point distance:

0mm   100mm

DESIRED:
ESTIMATED:
ACTUAL:

Curvature:

0   100

DESIRED:
ESTIMATED:
ACTUAL:

Percentage change in surface Area:

0%   100%

DESIRED:
ESTIMATED:
ACTUAL:

Percentage change in volume:

0%   100%
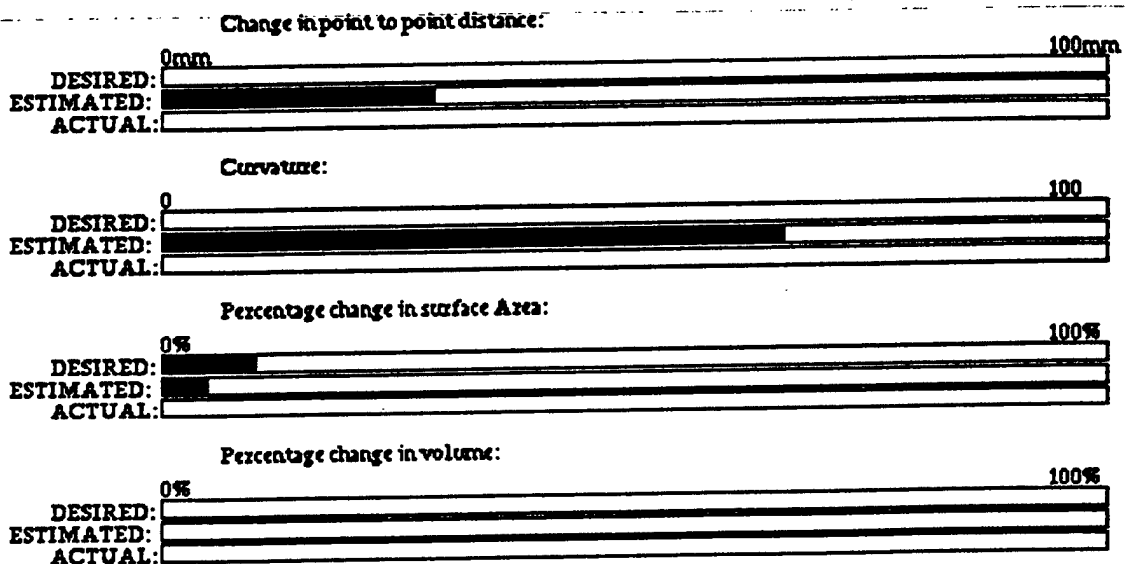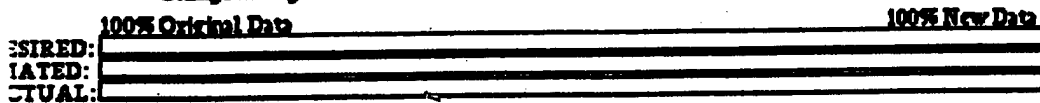
DESIRED:
ESTIMATED:
ACTUAL:

Figure 3. The system will make recommendations on the best data reduction algorithm for meeting the target goals. The interface will display the predict changes in measures.
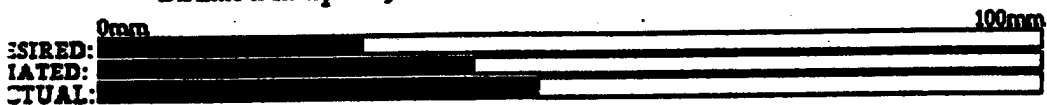
DATA MEASURES

Percentage reduction of data:

0%   100%

ESIRED:
IATED:
CTUAL:

Change in original data:

100% Original Data   100% New Data

ESIRED:
IATED:
CTUAL:

Distance to an implicitly defined surface:

0mm   100mm

ESIRED:
IATED:
CTUAL:

Statistical distance to a fitted surface:

0mm   100mm

ESIRED:
IATED:
CTUAL:

Maximum distance between points:

0mm   100mm

ESIRED:
IATED:
CTUAL:

GEOMETRIC MEASURES

Change in point to point distance:

0mm   100mm

ESIRED:
IATED:
CTUAL:

Curvature:

0   100

ESIRED:
IATED:
CTUAL:

Percentage change in surface Area:

0%   100%

ESIRED:
IATED:
CTUAL:

Percentage change in volume:

0%   100%
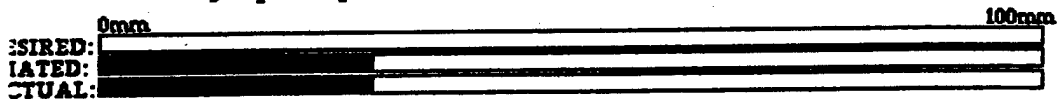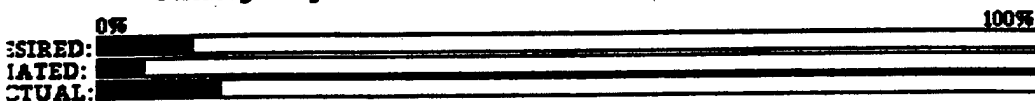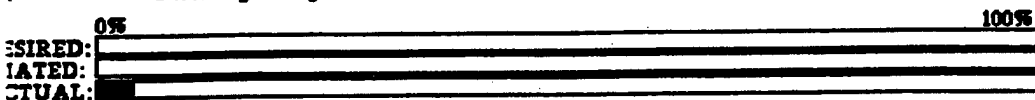
ESIRED:
IATED:
CTUAL:

tual changes after data reduction can be compared with the desired values and the estimated values. This
e computationally expense, and can be dropped once confidence in the estimating technique is attained.